FUNDAMENTALS OF RADIO TUBES

RECTIFIER CIRCUITS

LESSON ND 11

SPRAYBERRY ACADEMY of RADIO
ESTABLISHED 1932
PUEBLO COLORADO

The above view shows a grouping of radio tubes as made by the *General Electric Co.* Included are small receiving tubes, transmitter and special purpose tubes. Note the use of both metal and glass tube envelopes.

Fundamentals of Radio Tubes

RECTIFIER CIRCUITS

Lesson ND-11

This lesson begins your study of the radio tube as it is popularly known. All of your study in the preceding ten lessons has been pointed to this main objective. By means of tubes all of the basic concepts of your previous studies are put to work and made to have form.

You have learned of electrons which we believe to make up one of the basic charges of electricity; these under dynamic pressure constituting a flow of electrical current and the path over which they move presenting a certain amount of resistance. These studies have established concrete definitions of voltage, current and resistance.

Added to these basic concepts, are the ideas of electrostatic and electromagnetic lines of force, which are evidences of the two basic forms of electricity; namely, direct current and alternating current.

The quantities voltage, current and power are the units by which we measure and control electricity. These are made to act on circuits consisting of capacity, inductance and resistance which, among other things, gives us the terms of reactance, impedance and resonance, all of which have been given detailed treatment in previous lessons.

Most, if not all, of the foregoing *principles* in one form or another

have been known by scientists for several centuries. The development and expansion of these principles has been slow indeed as measured by one man's span of life. This has been due, no doubt, to lack of fast communication between contemporary investigators and because the discovery of one or more basic concepts was so closely linked with others yet to be discovered and formulated. As a consequence, events moved slowly until about the year 1900 when the pace accelerated and has continued in ever increasing tempo since.

In the search for a means of efficiently transmitting and receiving intelligence over great distances by means of wireless or radio, scientists were more or less up against a blank wall until the principles of the radio tube were discovered and put to work. The great need was for an economical device which would provide sensitivity, rectification (changing A.C. to D.C.) and the suitable generation of electrical power in a form which resistance, inductance and capacity could handle efficiently. The gradual development (a span of 50 years) of the radio tube has made all of this possible—is what makes possible the *broad field of radio* as we know it today.

Past history of events leading up to present-day radio standards would fill many volumns. Since even a portion of the past history cannot be given here, and since busy practical radio men have no need of historical data, we will not even attempt to go into past history except to mention one or two comparatively recent outstanding events which have special significance.

The Need for a Radio Tube Established

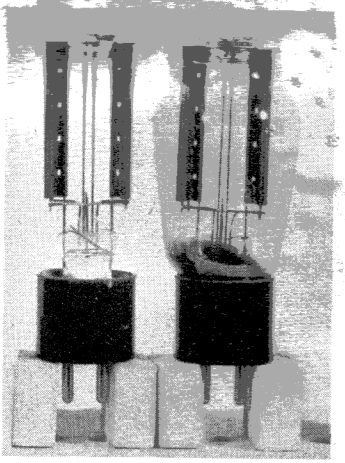
To give our story direction, it may be said the efforts of early investigators were directed toward some means of changing high frequency radio signals (any frequency above 100,000 cycles) to audible low frequencies. This being proven beyond doubt, the search pointed toward the discovery of a device which would be sensitive enough *to change very weak high frequency signals* to low frequency signals, and in that way, ultimately permit the human ear to hear sound pressure waves of a frequency suitable for the human ear. The result of early investigations was the development and perfection of a radio tube consisting of two elements known as a *filament* and a *plate*. Today, we recognize and know this to be a *diode tube*, which means a radio tube consisting of two elements —but more about this later.

A Return to the Electron

You have learned that *all forms of matter* (solids, liquids and gases) are made up of molecules, atoms and electrons. The electrons together with the nucleus make up the atom; the atom or atoms, in turn, make up the molecules and the number and arrangement of the atoms and molecules make up all known substances.

The atom is supposed to consist of a central mass, called the nucleus, around which are grouped several layers of electrons; the exact number depending on the type of atom. The nucleus has an inherent positive charge and the electrons, regardless of the number of them grouped around a nucleus to form an atom, all have an inherent *negative charge*. The electrons revolve about the nucleus in well defined orbits. Although the atom as a unit is made up of two inherent opposite charges of electricity, the electrical effect of it is not apparent external to the atom because the amount of positive charge just balances the negative charge.

Some of the electrons on the outer fringe of the atom may be caused to leave the influence of the positive nucleus when proper force is applied to the atom. These removable electrons are known as *free electrons*.



Shown above are the construction details of the 5Z3 full wave rectifier tube as made by the *National Union Radio Corp.* Further on in the lesson you will find full information on this type tube.

Other electrons located near and those contained in the nucleus are more tightly bound to it and are thus known as bound electrons. It requires a tremendous force to remove one or more of the bound electrons from the influence of the nucleus. In radio, we are not interested so much in the bound electrons but rather in the free electrons, because the drift of these from atom to atom makes up what we identify as the flow of electricity.

Some materials have more free electrons than others, and we can cause them to drift from atom to atom much easier than is the case with certain other materials. Examples of such materials are silver, copper, aluminum, etc. This refers, of course, to the materials used as electrical conductors wherein a source of voltage is connected to them and this, in turn, causes a flow of electron current.

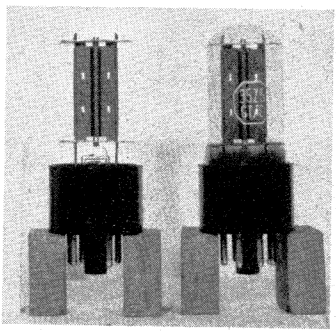
Electron Current

A flow of electron current means that free electrons have been released from the influence of the atoms with which they were originally associated. So far in your S. A. R. course you have been taught to think of dynamically moving electrons as those

which [illegible] metalic [illegible] it is not [illegible] may be made [illegible] from one point [illegible] trons may also be [illegible] *into space* away [illegible] source as, for [illegible] conductor of the proper [illegible] electrons may be made to leave a suitable conductor in [illegible] streams much in the same way steam may be made to leave a boiling teakettle.

There are three ways in general in which electrons may be *forced to leave a conductor.* These are: (1) by applying heat to raise the temperature of the conductor; (2) by photoelectric effect wherein light rays will release electrons from certain sensitive materials; (3) by being knocked out of the conductor by impact caused by other electrons bombarding the conductor. This release of electrons from a conductor is called *electron emission.* From a radio tube view point, the emission of electrons by *heat* is the most practical, and is the method most generally employed. Thus the word *thermionic emission* is in common us—the word *thermo* referring to heat and *ionic* to electrons (in a broad sense).

Radio tubes are, therefore, often referred to as *thermionic tubes.* Another term often employed is *elec-*



This photo shows a 35Z5GT/G half wave high vacuum type rectifier tube. This type of tube has its greatest application in small A.C.-D.C. sets. *Courtesy National Union Radio Corp.*

tronic tubes. The word "thermionic" is used most generally in a technical sense while "electronic" refers to the broad field of industrial and radio applications for tubes. Radio is just one branch of a much larger field known as electronics.

Vacuum Necessary

Nothing particularly useful can be accomplished by merely causing electrons to be emitted from a conductor in *ordinary open air.* To be sure, such a thing may be accomplished, but no useful work is done. To be useful, there must be some method of control over the electrons once they are released from a conductor.

Let us see why this is true. *All matter that is solids, liquids* and *gases* are themselves made up of molecules, atoms and electrons. The common air we breath is a *gas* made up of nitrogen (78.03%), oxygen (20.99%) and five inert gases of approximately .98%. These are Argon, Neon, Helium, Krypton and Xenon. Now, if in ordinary air electrons are forcibly emitted from a conductor, they will collide with the atoms and molecules of the gases which make up air, perhaps upsetting their electrical balance temporarily. Very quickly, however, electrical balance will be restored, and either those electrons emitted or others nearby will be attracted to the emitter to restore balance. In other words, in open air there are no nearby positive charges to attract free electrons and, as a consequence, the electrons return to the emitter because having *lost electrons* it is the only nearby positive charge existing to attract free electrons. Thus it can be assumed that in open air any emitted electrons are immediately returned to the emitter and no useful purpose has been served.

At this point it is well to remember that an electron is inherently charged negative and will be attracted to any nearby positive charge if at the same time its own atomic attraction is not too great. Thus, if no such positive charge exists to attract it, it will not move from the atom with which it happens to be associated. The application of voltage will cause free electrons to move in a conductor and the application of heat to certain sensitive conductors will cause them to emit electrons. It is important to understand here that it is *heat alone* that causes the emission of electrons—the *kind of heat* is not important as far as the production of emitted electrons is concerned. Any kind of heat that will raise the temperature of a given conductor high enough will do just as well as any type of heat. It becomes then a question of supplying heat in the most efficient and convenient form. Heating a conductor by causing electricity to flow through it is the common accepted method of supplying heat to bring about the emission of electrons. We will go into detail about this further on in this lesson.

You have seen how the mere emission of electrons alone is not very useful. The problem then is to find a means of using the electrons after they are emitted. Thomas A. Edison, in the early days of his experimentation (1883) with the incandescent light bulb, discovered a means of using and controlling emitted electrons from a hot surface. He used a *sealed* glass bulb from which most of the air atoms and molecules had been *removed by means of a suction pump.* In other words, he was employing a *near vacuum* (absence of air and other gases) in his light bulb. With a vacuum there are few gas atoms and molecules for the emitted electrons to encounter. Thus they are free to leave the emitter (within limits) in all directions. Edison's investigations showed that early failures of his light bulb were due to the positive leg of the conductor burning in two and so ending the life of the bulb. This was due to the positive leg of the con-

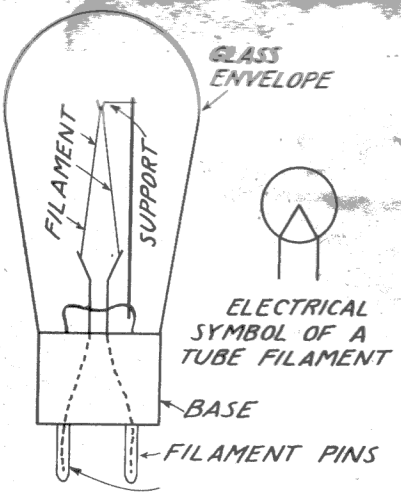


FIG. 1

ductor within the lamp attracting free electrons. More investigation by Edison resulted in placing an extra metal element within his glass bulb which was made positive by an external connection. *Tests showed that a current flow was established within the bulb from the emitter to the extra element despite the fact that considerable space existed between them.* Thus for the first time was demonstrated the basic principle of our modern radio tubes. Edison in his zeal for the perfection of a satisfactory electric light made no use of this discovery but did record it in his notebook. It remained for others to investigate and make this discovery useful.

The Discovery of the Diode Tube

Dr. J. A. Fleming of England, in his search for a suitable rectifier or detector for high frequency wireless signals, investigated the "Edison effect" and eventually worked out a device which gave the results he wanted. He used a sealed and evacuated glass bulb containing an electron emitter and a small metal element. This was called a valve, and today radio tubes in Europe and other parts of the world are called valves. [illegible] as *vacuum tubes*. Radio men [illegible] to them as *tubes*.

Today we call [illegible] a *cathode* and [illegible] within the tube an [illegible]. The tube with an [illegible] plate as described is called a [illegible] because it has two useful elements.

In the modern tube, the emitter or cathode may be a tube filament (a special type of ribbon [illegible]) or a separate cathode element may be employed wherein a filament is used to *heat the cathode indirectly*. All of this will be brought out in careful detail later on.

Modern tubes employ filaments which are sealed in a vacuum inside the envelope of the tube. See Fig. 1. The first tube envelopes were made of glass. These resemble the glass envelope of the familiar incandescent or electric lamp. More recently it has become the practice to use metal envelopes instead of glass—we will return to tube envelopes, filaments and cathodes later. For the present consider the fundamental "Edison effect."

The things which Edison noted were these:

(1) If a current meter was connected between the plate and the positive side of the filament (outside of the glass envelope), a current flowed through the meter *when the filament was lighted*. Figure 2 shows the circuit. Note that there is *no direct metalic contact* within the tube between the plate and filament.

(2) If a battery was connected in series with the meter and the circuit arranged as shown in Fig. 3, the

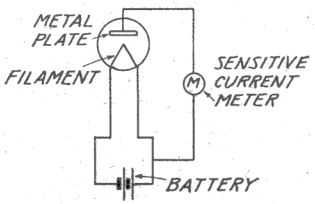


FIG. 2

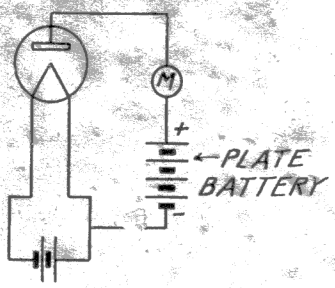


FIG. 3

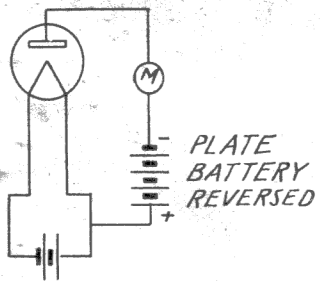


FIG. 4

current flowing in the circuit was much higher than before.

(3) If the plate battery polarity was reversed as shown in Fig. 4, *no current flowed through the meter.*

Two years after Fleming first applied his vacuum tube for use as a detector, another inventor, Dr. Lee DeForest, *introduced another electrode of metal between the filament and the plate.* This extra electrode is called a *grid.* See Fig. 5. Note the difference between this and Fig. 2, in which only the plate and filament are shown. This *new type of vacuum tube* was found to be superior for detecting weak signals. Later it was found that it could also be used to *amplify* (strengthen) *weak signals.* In a succeeding lesson you will take up the study of the *grid* and the amplifying action of a tube. This lesson will be confined to the study of *diode* and *rectifier* tubes.

The essenital uses of vacuum tubes today may be classified into four main groups.

(1) To serve as *rectifiers* for the purpose of converting alternating current to semi-direct current.

(2) To serve as *detectors* for separating signals which are composed of a combination of several frequencies.

(3) To serve as *amplifiers* of weak signals of any frequency.

(4) To serve as *generators (oscillators)* for the purpose of converting direct current into alternating current of any frequency.

Rectifier Tube Principles

In the modern A.C. operated radio set there is a definite need for a rectifier tube. These are available in several types. In general, they may be divided in two classes. (1) The type which rectifies one half of an A.C. cycle. These are called *half wave* rectifiers. (2) The type which rectifies both halves of the A.C. cycle. These are called *full wave* rectifiers. The word "rectifier" in radio means a device which will change alternating current into semi-direct or direct current. In addition, as you will learn later, filters are used to smooth the rectified current to where it is essentially a *direct current.*

The characteristics of radio tubes are such that they require *high voltage direct current* for their operation. The usual voltage of power lines with which our homes are wired varies from 110 to 125 volts. Radio tubes, on the other hand, require up to 300 volts D.C. and higher. Thus the voltage must not only be in-

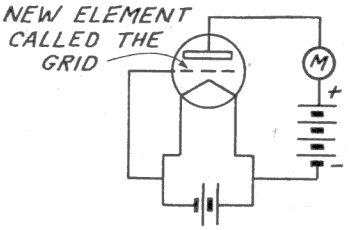


FIG. 5

creased [illegible] must also be changed from A. C. to D.C. As you will learn later, a *power transformer* is used to increase the voltage to the required value. A rectifier tube then changes the high voltage from A.C. to D.C. Thus it should be clear that every other tube in the radio set is dependent on the rectifier tube. If it doesn't function, none of the other tubes will perform their required task. *Hence the need for a rectifier tube is clearly established, and is why you need to study them in careful detail.*

Radio tubes are identified and known by numbers or by a combination of numbers and letters. At present, there is a definite system known as the R. M. A. (Radio Manufacturers Association) tube code. You will be given information on this code system later. For the present, we will merely give the identification numbers or letters and leave it to other lessons to explain about tube types in general. The first tube to be described is the type 81—a half wave rectifier.

This tube contains the same number of elements used for the early work on vacuum tubes; namely, the *filament* and a *plate* which are *sealed in an exacuated chamber* (envelope) and are insulated from each other—that is, space exists between the two elements. The leads are brought to pins on the bottom of the insulating base which, in turn, is cemented to the glass envelope as shown in Fig. 1.

The filament of the type 81 tube operates at a voltage of 7.5 volts. When this voltage is applied to the filament terminals, the current which flows through the filament circuit is about 1.25 amperes. As this current flows through the filament (in this case the filament is the emitter) it becomes heated and *electrons are shot off from the surface of the filament wire in all directions.*

On the *surface of the filament wire* there is a *layer of metalic oxide* which [illegible] has the [illegible] electrons [illegible]

Tube fil[illegible] electron emit[illegible] tungsten, th[illegible] metals coated [illegible] oxides. Tungsten [illegible] nated with thoria [illegible] substance) perm[illegible] at lower temperatures [illegible] C as against 2500° for pure tungsten) which gives longer tube life. Coated filaments operate at about 800° C. The coating is relatively thick as compared to the size of the filament wire. The earth oxide coatings are usually made from barium, strontium and calcium. The exact type of filament used in a given tube design is controlled by requirements of the tube, length of tube life wanted, etc.

To return to the 81 type of tube, if the plate which is sealed in the same envelope with the filament is made *positive* with respect to the filament *some electrons* will be *attracted to the plate and will flow over to it from the filament, through the space within the tube itself.* As the value of the plate voltage is increased, the number of electrons flowing over to the plate will increase until such time as all of the electrons *being released* from the filament surface *are flowing over to the plate.*

When this condition is reached, *no more electrons* will be drawn over to the plate *regardless of how much the plate voltage in increased.* The only way the *number of electrons can be increased,* or the *plate current as it is commonly called,* is to *increase the number of electrons emitted from the filament surface.* The only way this can be easily accomplished is to *raise the temperature of the filament.* Then, as the plate voltage is increased, the plate current will increase again until *all of the electrons* being liberated from the filament surface *are again* being drawn over to the *plate.* The point at which this occurs

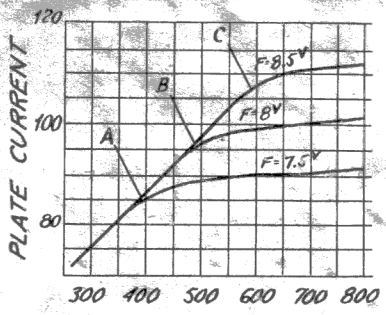


FIG. 6

is called the *saturation point*. Figure 6 is scaled to show the saturation point for the type 81 tube at three different filament voltages; namely, 7.5, 8 and 8.5 volts—note the recommended operating filament voltage for the tube is 7.5 volts.

Types of Heater — Cathodes

The type 81 tube is known as a filament or direct heater type of rectifier, since the active electron material has been *deposited directly on the surface of the filament*. There is another type of filament-cathode construction which is employed for rectifiers and also for other types of tubes —one in which the active electron emitting material *is not deposited on the filament wire, but rather is deposited on a metal sleeve,* which surrounds the filament but *does not touch it*. This is known as the indirect heater type of construction. The sleeve is heated by means of a separate filament wire which is arranged in one of several different forms *inside* of the sleeve (cathode). The filament (or heater as it is often called) is extremely well insulated from the sleeve, even at the operating temperature of the heater. Thus the two elements are *entirely separated from each other*. There are three forms of filaments generally employed: the *hairpin, folded* and *reverse* coil types. These are employed for various tubes, depending upon the particular design of the tubes. The three types of filament construction are illustrated in Figs. 7A, 7B and 7C.

The electron emitting surface, whether it be the filament, itself or the insulated sleeve, *is called the cathode*—meaning negatively charged. The plate is often called an *anode*—meaning positively charged.

Figure 8 shows a drawing of the actual layout of the elements in a half wave rectifier tube such as the type 81. Figure 9 shows the details for a full wave rectifier tube such as the type 84.

You will note that the only difference between the two types of tubes is that one of them, the 84, has two plates and an *indirect heater* cathode element. The 81 has only one plate and a filament or a *direct heater* cathode.

Half Wave Rectifier Tube Circuits

An elementary A.C. power supply for a radio receiver in which a tube is used to change the A.C. to pulsating D.C. will now be considered. Such a power supply is necessary because the A.C. voltage from the 110 volt supply line is not suitable for operating a radio receiver. If raw A. C. (direct from the power lines) were used to operate a receiver, there would be a *tremendous hum* —no one would enjoy listening to the signal.

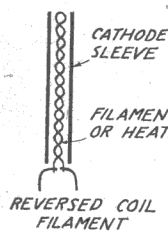


FIG. 7A

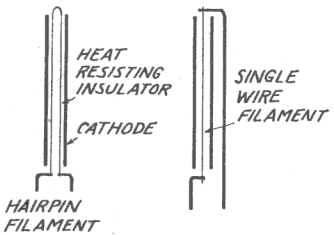


FIG. 7B

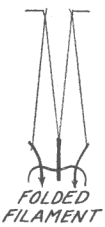
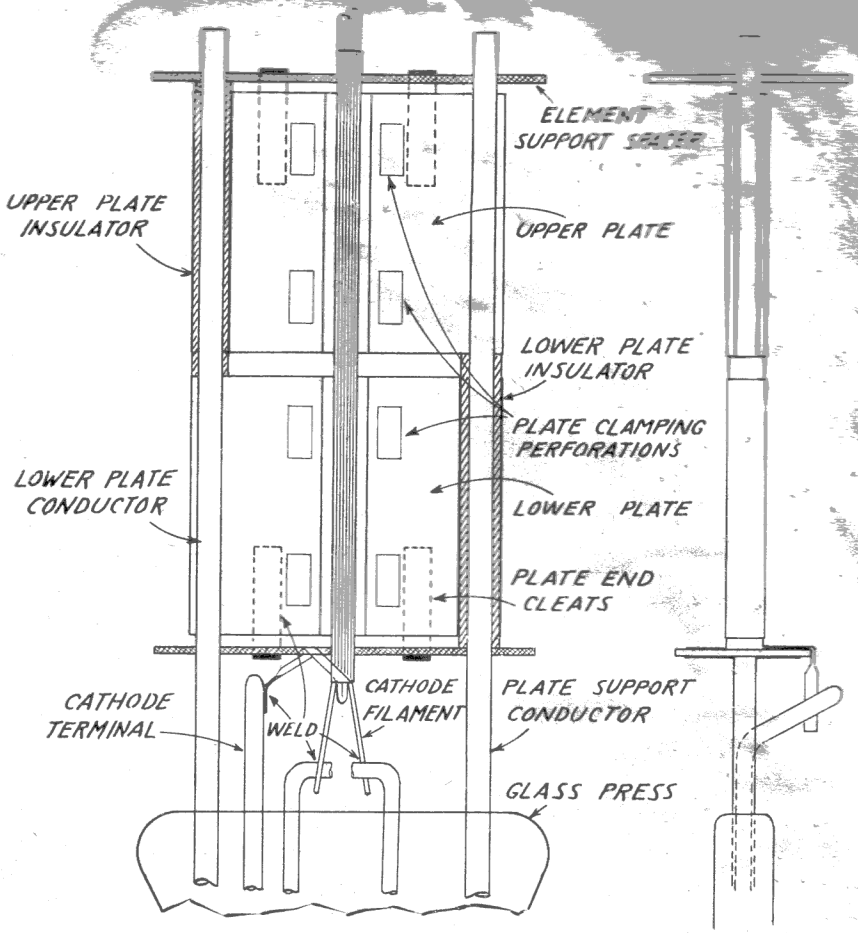


FIG. 7C



TYPE 84 TUBE

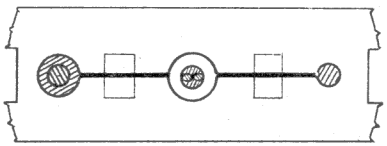
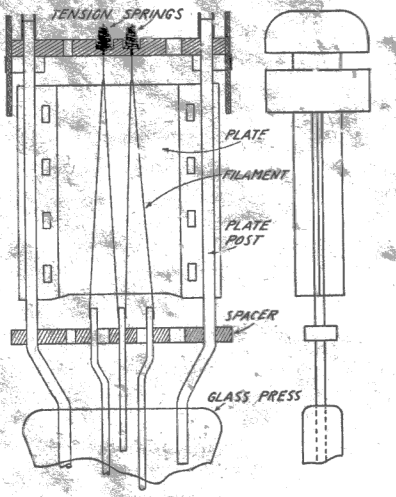


FIG. 9

There is still another reason why a power supply is necessary. The A.C. power supply line itself provides voltage from about 110 to 125 volts. This voltage is not usually high enough to operate a receiver, since voltages up to 300 volts and more are required to operate the average radio receiver.

Therefore, a power transformer is required which will step-up the voltage to the required value. You will remember in your studies of magnetism and inductance that an elementary transformer was described, having two windings of wire on a suitable form. You will recall, too, that with A.C. connected to one winding,



TYPE 81 TUBE

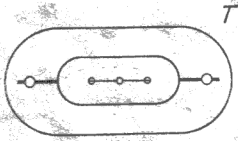


FIG. 8

a voltage could be induced in the second winding.

This same principle is made use of in a *power transformer* for the power supply of a radio receiver. This transformer consists of two or more wire windings on an iron core. Other lessons will give more details on transformers. The electrical symbol for this type of transformer is shown in Fig. 10.

The A.C. voltage applied to the primary winding is constantly changing. Therefore, the magnetic lines of it are constantly building up and reducing. This causes a voltage to be built up in the secondary winding, as was explained in your lessons on magnetism and inductance.

Since the secondary winding has many more turns than the primary winding, the voltage in the secondary circuit is considerably higher than the voltage in the primary circuit according to the law of *turns ratio* between

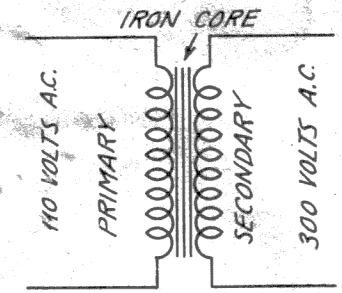


FIG. 10

windings as explained further along in your course.

Figure 11 shows the elementary circuit. It consists of a transformer having a 115 volt primary and two secondaries. The low voltage secondary supplies 7.5 volts to the rectifier filament, while the other secondary supplies a maximum of 500 volts across the plate and ground as indicated by the letters A-B in Fig. 11. While the ground connection is not essential to the operation of the circuit, it will greatly assist in a better understanding of its operation. The D.C. voltage at the ground connection does not change, and is always zero. It is used here simply as a convenient reference point.

Some type of load circuit is needed so that the electron path may be completed external to the tube. A load circuit is actually part of a rectifier circuit just as an electric lamp or transformer becomes part of the house wiring circuit when put into operation. We have, therefore, symbolized the load as a resistance R, in Fig. 11. Normally this load in a radio receiver

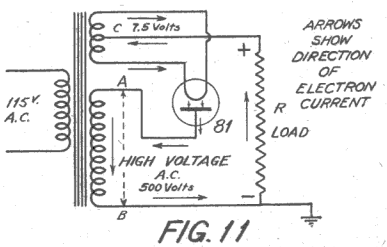


FIG. 11

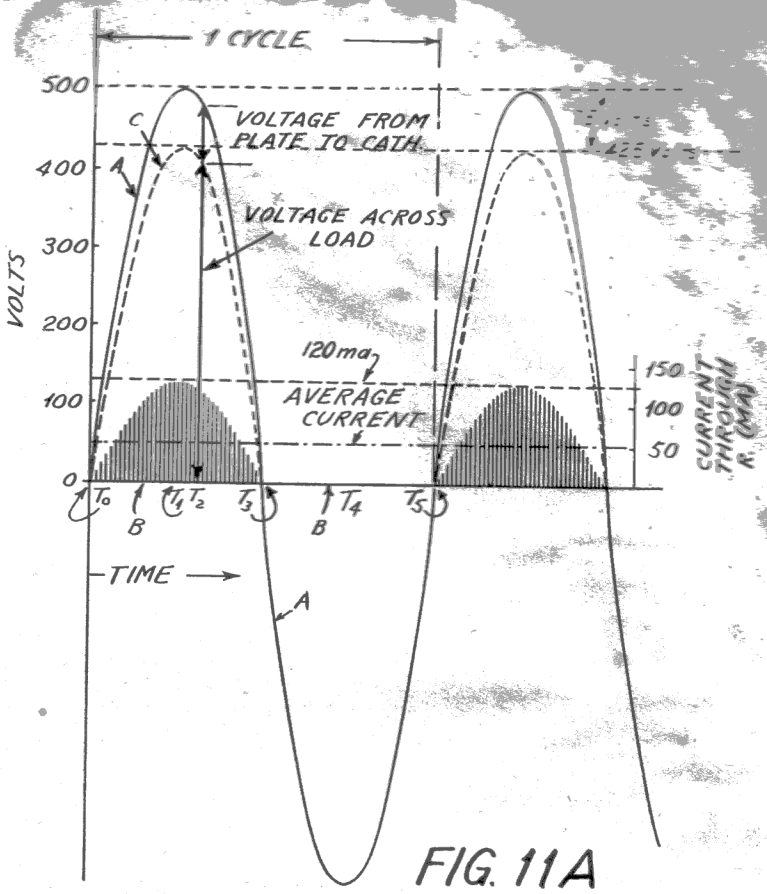


FIG. 11A

represents the other tubes which the rectifier supplies with D.C. voltage. We now have the three elements of a rectifier system, the supply voltage, the rectifier tube and the load correctly wired so power will be distributed properly. The filament winding is simply incidental to heating of the filament. It does, however, *act as a conducting circuit* for the rectified current.

When the primary is connected to the 115 volt A.C. power line, an A.C. voltage will be induced in both of the secondaries of the transformer. The filament secondary voltage, 7.5 volts, simply serves to heat the filament and needs no further consideration at this time.

Point B of Fig. 11 is grounded (standard practice) and remains at zero voltage (with reference to D.C.). Points A and B of the high voltage winding will become positive and negative as the A.C. induced voltage in the secondary is developed. Starting from zero, let us see what happens to the A.C. wave form as terminal A becomes positive. The results, showing conditions for half wave rectification are plotted in Fig. 11A.

Starting at time T0 on the base line at the left, note that all voltages and currents are zero. Now consider that terminal A (Fig. 11) starts to advance in the positive direction (upward) and remember it is connected to the plate of the tube. The solid line curve marked A in Fig. 11A

Above is shown two types of half wave mercury vapor rectifier tubes as made by RCA. These tubes are usually used in transmitters. Different sizes are used because of different power requirements.

shows how the plate becomes increasingly positive as it builds up to 500 volts. It becomes positive very rapidly, reaching a maximum of 500 volts at time T1, or at the end of the *first quarter of the cycle*. The voltage scale at the left of Fig. 11A shows the plate to ground voltage from zero on up to 500 volts.

Now as soon as the plate in Fig. 11 rises above zero voltage it starts to draw electrons (current) from the filament or cathode. At the beginning of this cycle (T0) the cathode was also at zero voltage (average), as there was no voltage acting on it other than that used to heat it, which for the present we may disregard.

As soon as electrons are drawn away from the negative cathode by the positive plate it becomes more and more positive, the cathode having lost electrons becomes somewhat positive itself. If the cathode could not be supplied with more electrons as it loses them, it would become just as positive as the plate, but the load resistor completes the cathode circuit to ground through which electrons can be drawn by the cathode to replace those lost.

It is important to remember at this point that the load R in Fig. 11 is in reality several tubes in a complete receiver. It can, however, be symbolized by a resistance R to simplify the consideration. Actually, the several tubes may be considered as separate resistors through which the rectified current flows. You must remember, too, that current leaves the rectifier at its plate, flows through the other tubes and returns back to the cathode of the rectifier tube. In other words, there must be a complete circuit before current may flow, because it is necessary for electrons to *return to the cathode* to replace those emitted by it inside the tube.

The plate circuit of the rectifier (space within the tube between the cathode and plate) and the load R, are simply in series with a voltage impressed across them. The applied voltage rises, and the voltage across the tube (plate to cathode) and the voltage across R both rise accordingly. The sum of the tube voltage (plate to cathode) and the load voltage (across R), of course, equals the applied voltage. However, the resistance to current flow within the tube is much less than the load resistance in practical circuits. In view of this, the effective D.C. voltage from plate to cathode (across the tube as a whole) is less than the voltage across R—the load.

The dash line C in Fig. 11A shows how the cathode voltage changes. With this information, let us see what the conditions are at the end of the first quarter of the cycle, or at time T1. The plate voltage has now reached 500 volts, its maximum or *peak value*. For this condition, note the cathode voltage is at about 425 volts as estimated from the voltage scale at the left in Fig. 11A. According to the scale of current in ma. at the right, the current (denoted by the shaded curve) is

estimated at about 120 ma. This, of course, is its maximum value as shown by the curve.

At this instant, since the total voltage is 500 volts and the total current is 120 ma., the total internal resistance of the tube's plate circuit and the load R would be equal to 500 divided by .12 or 4167 ohms. Now, if the plate is at 500 volts and the cathode at 425 volts, it is obvious that there are only 75 volts or 500 minus 425 from plate to cathode at this instant. With only 75 volts from plate to cathode and a current of 120 ma., the internal plate resistance of the tube is 75 divided by .12 or 625 ohms. The balance of the resistance is that of the load R or 4167 minus 625 equals 3542 ohms. The voltage at the cathode (425) is, of course, the voltage impressed across R. In other words, there is a voltage drop across the tube of 75 volts.

The *internal plate resistance* of any high vacuum rectifier *does not remain at one value but varies to some extent with the amount of current flow through it.* Thus a radio tube does not follow *ohms law*. It is important to remember this principle. For example, the 81 plate resistance will *increase* as the current flow through it *decreases*. It will be around 1000 ohms when carrying only a few milliamperes of current and down to about 500 ohms when carrying more than 120 ma.

During the *second quarter cycle* (time T1 to T3 in Fig. 11A) the plate voltage reduces as determined by the wave shape of the transformer induced voltage. Accordingly, the cathode voltage reduces and the plate current reduces. All of them reach zero at the same time (T3) at the end of the first half cycle.

For the second half cycle, the induced voltage at point A in Fig. 11 becomes negative as the polarity of the primary current of the transformer is now changing. Although the plate is connected to a high negative voltage (500 volts—peak—during the third quarter cycle—time T3 to T4 (peak of the negative half cycle) no current flows in the tube or in R because the cathode remains at zero voltage. The plate, because it is at minus 500 volts, *strongly repels electrons from the cathode and electron current is completely stopped.* This is true also of the last quarter cycle in which the plate, still negative, is reducing from minus 500 to zero volts. Thus we have the conditions for rectification, since current can only pass through the tube in one direction.

The cathode voltage and the plate current remain at zero during the last half cycle (T3 to T5) *and no use is made of the high negative voltage developed.* In this case, terminal B of the transformer changes to 500 volts positive but the effect is nil because current cannot flow through the tube in the reverse direction. This voltage may be compared to the end of an open wire or switch contact which has been disconnected from the circuit—the voltage is present but no current is drawn and no use is made of it.

All of the other cycles are exactly like the one just described, and the current flow through R has the form shown in Fig. 11A. It flows in intermittent pulses and has very little practical use in this form. The voltage across the load indicated by the curve C in Fig. 11A is also in pulses separated by zones of no voltage at all, such as from T3 to T5 every half cycle. Half of the time no voltage whatever is present, while during the balance of the time the voltage is changing from zero to +425 volts and back again to zero.

For application to vacuum tube amplifier circuits this voltage is not the slightest bit better than applying A.C. voltage directly from the high voltage winding (Fig. 11) directly to the amplifier tube plate circuits.

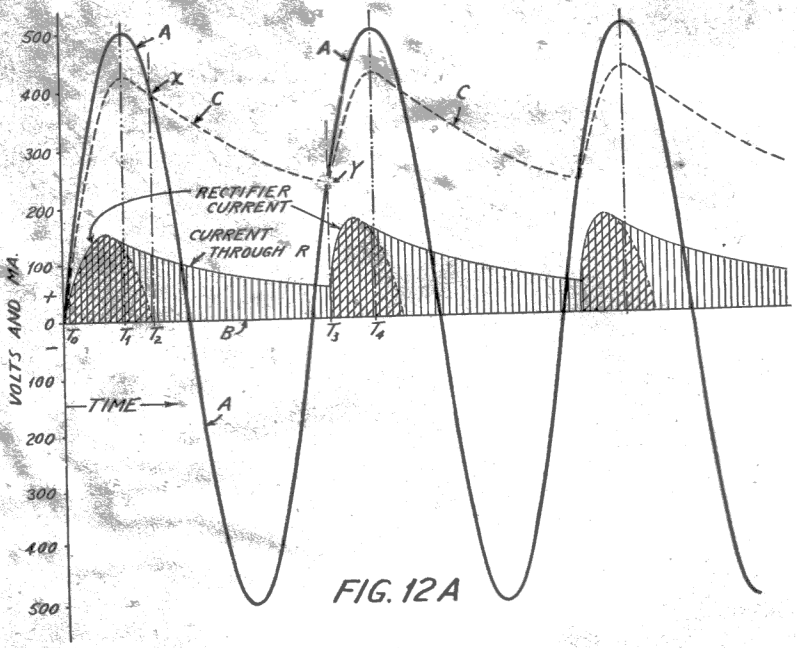


FIG. 12A

The amplifier can make no more use of the negative half cycle than the rectifier and the rectifier could just as well be omitted if this was as far as we could go in producing a satisfactory D.C. output.

What we desire from an A.C. power supply is a steady D.C. voltage output (not an interrupted one as in Fig. 11A) or, at least, one as steady as possible.

Adding a Condenser to the Rectifier

Next we will explain how the rectified current is made more smooth and suitable for operating other radio tubes. The object is to decrease the humps of the current curve in Fig. 11A. This is accomplished by using a 4 mfd. condenser across the load resistance R. Its effect on the voltage across the resistance and the current through it will now be explained. The circuit of this arrangement is shown in Fig. 12 and the action resulting is given graphically in Fig. 12A. This latter figure merits your close study. During the first quarter cycle conditions are very much the same as before for Fig. 11A. However, the current drawn by the load R this time is somewhat greater, *because the condenser is part of the load* and its charging current (due to the condenser reactance) is added to that drawn by the resistor R. The solid arrows by the condenser leads in Fig. 12 indicate the direction of the charging current, while the dash arrows indicate the direction of the discharging current as will be brought out later.

After the first quarter cycle note in Fig. 12A that conditions of voltage and current are very different

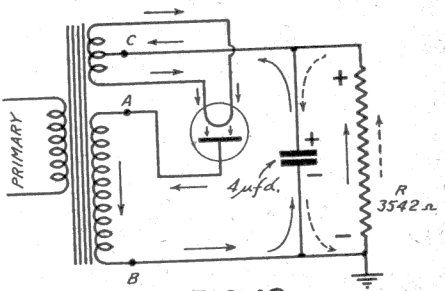


FIG. 12

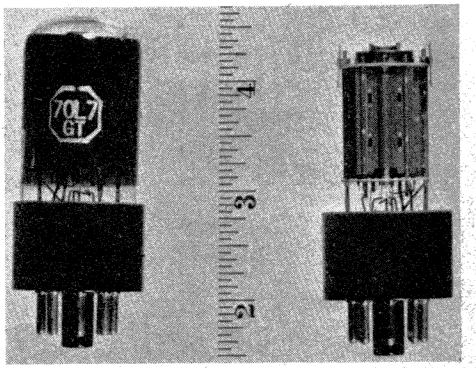
from those shown in Fig. 11A except for the voltage at A which goes through exactly the same variation as in Fig. 11A. In the first quarter cycle in Fig. 12A from time T0 to T1 the rectified current supplying load R and charging condenser C reaches a maximum and, as the condenser reaches full charge, the current reduces somewhat at the end of the first quarter cycle at line T1. At this time no more current is flowing into the condenser because the cathode voltage C has reached a maximum value and does not increase further to charge the condenser to a higher value of voltage.

From the study of condensers you have learned that once charged, a condenser tends to keep its charge. Since the condenser positive terminal in Fig. 12 is connected directly to the cathode, it will keep the cathode charged to the same value of voltage to which the condenser has been charged, due to the rise of voltage in the A.C. wave form. The dash line C in Fig. 12A is, therefore, the condenser voltage and the resistor voltage as well as the cathode voltage, because these are all connected together. Because of the charge retained by the condenser, the cathode voltage does not drop to zero as it did in Fig. 11A when the plate voltage of the rectifier reduced to zero but reduces more gradually as indicated in Fig. 12A by the dash line C.

The fact that this line is sloping downward shows that the condenser is discharging (current flows in the direction of the dash arrows in Fig. 12) *and this means that current is flowing out of its negative (grounded) plates and into its positive plates.* This discharging current of the condenser flows through the resistor R in Fig. 12 because this is the only path through which it can possibly flow. At about the middle of the second quarter cycle at time T2, note carefully at point X that the plate voltage A has reduced down to the exact value of the cathode voltage. What happens when the plate is no longer more positive than the cathode? *Plate current can no longer flow.* At point X in Fig. 12A voltages *A and C are equal* and at the same time (T2) the *rectified current* drops to zero. From this time all the way to time T3, the beginning of the second cycle, condenser discharging current is flowing through the resistor. Thus when the rectifier stops supplying current the condenser comes into action (due to previously being charged) and starts to fill in the gap of the current wave form. *It is by this action that the condenser makes the current more smooth than it was in Fig. 11A.*

The curves in Fig. 12A are accurately scaled to correspond to the values of condenser C and resistor R. Thus, if the condenser is originally charged to 425 volts it will discharge to about 225 volts (point Y) at time T3. The current through R will likewise be about half what it is at time T1.

At time T3 of Fig. 12A, we have another important action at point Y. The plate voltage has gone through its negative half cycle and is advancing in the positive direction again (curve A). At time T3 it reaches point Y, about 225 volts (left scale)



The above photo shows the details of the 70L7GT tube as made by *Raytheon.* This tube is of the multiple purpose type combining the features of rectification and beam power amplification.

and in rising becomes equal to the condenser voltage. It soon exceeds the voltage at the cathode which is maintained by the condenser and again starts to charge the condenser to a higher value and so supply the load resistor. Then at time T4, the same condition as at T1 takes place; namely, the condenser reaches full charge and draws no more current, the cathode and plate voltages reach maximum, and the rectified current starts to drop below that of the condenser discharge current.

Summing up these conditions, we find in Fig. 12 that the *average voltage* across R is somewhat greater than for Fig. 11, and that there is *always* a voltage across R and a current through it. This advantage has been gained through the use of condenser C in Fig. 12. The current is still a long way from pure D.C., as the latter would be indicated by a straight line. Compare the improvement of the rectified current in Fig. 12A over that shown in Fig. 11A.

Full Wave Rectification

Obviously, for further improvement, the next thing to do is to take advantage of the other half cycle which is not used in a half wave rectifier system. To accomplish this all we have to do is to set up another transformer and rectifier exactly like the one in Fig. 12 and connect its high voltage winding so that when the plate terminal A of the first transformer becomes negative, the plate terminal of the new winding will be as much positive. These connections are shown in Fig. 13. The second plate terminal is marked D. The transformers are identical except that the high voltage winding on transformer T2 is connected just the opposite to that on T1. The upper end B of the high voltage winding B-D on T2 is connected to ground while the lower end D is connected to the plate of the second 81 tube marked V2. Because of this connection, as

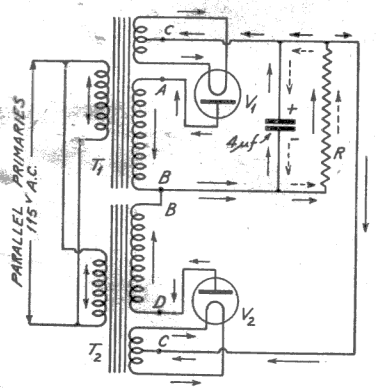


FIG. 13

terminal A becomes negative, terminal D will become as much positive as the cycle changes. Of course, while A is positive (first half cycle) D will naturally be negative. Now during the time that A is negative (second half cycle) D will be supplying the condenser and resistor exactly as A did.

Note that since terminals B of both windings are connected to a common point -windings A-B and B-D may as well be *one single winding with a tap at B*. Also since C of both filament windings are connected to a common circuit, a single filament winding with larger wire (same number of turns) may be used to supply both tubes V1 and V2. Instead of having two primaries, moreover, only one primary winding using larger wire may be used to supply voltage or power to all of the secondaries. The result of all of these changes is shown in Fig. 14. This provides a small compact *full wave* rectifier circuit. Half of winding A-D

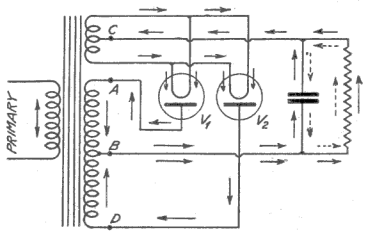


FIG. 14

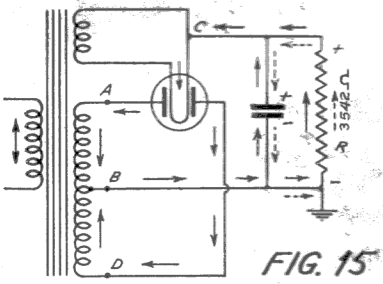


FIG. 15

in Fig. 14 supplies the voltage for rectifying one-half of the cycle, while the other half serves the same purpose for the second half cycle. This arrangement is called *full wave rectification*. In Figs. 13 and 14 the arrows show the direction of current flow (assume current flow to be from negative to positive) for a complete cycle of operation. The dash arrows, as usual, show the direction of the condenser discharge current.

The elements of tubes V1 and V2 in Fig. 13 are easily combined in one tube such as the type 80 as in Fig. 15. The 80 tube and its electrical equivalent, the 5Y4G, will not handle quite as much current per plate as two type 81 tubes nor will its plates accomodate as high a voltage.

In Fig. 15 the filament center tap connection has been omitted, as it is satisfactory and much simpler to attach the load and condenser to either filament terminal as at C in Fig. 15. Too, the omission of a center tap of the filament winding makes for a more economical power transformer.

A careful inspection of Fig. 15A will show the advantage of a full wave rectifier over a half wave rectifier. Be sure to study this figure in careful detail. Here we have used the same voltages as for the 81 rectifier. This represents the maximum recommended conditions for the 80, the 5Y3G or the 5Y4G, while the 81 tube can be used with about 1000 volts. The conditions shown for the 81 tube in previous figures were thus considerably under its maximum rating.

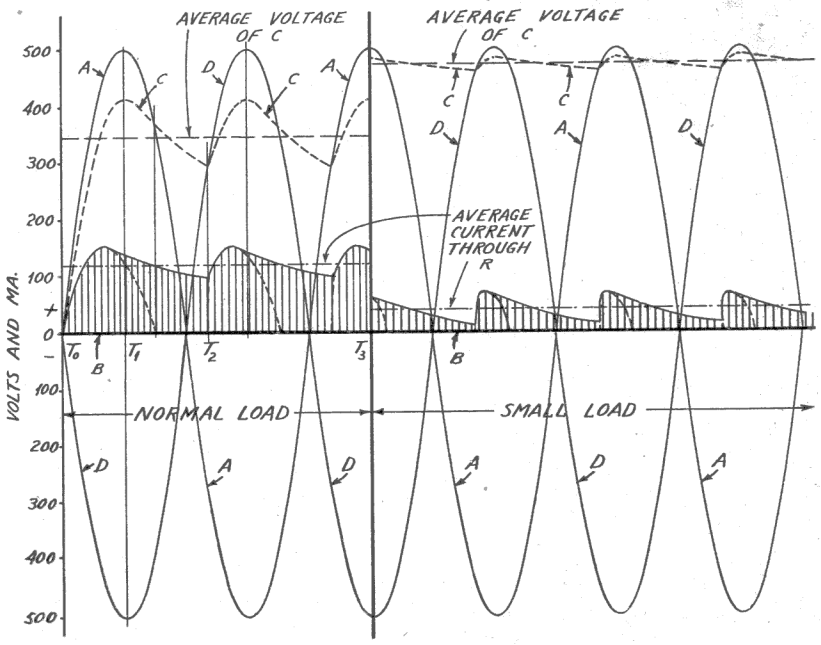


FIG. 15 A

For the first quarter cycle (T0 to T1) in Fig. 15A the action is identical to that in Fig. 12A for the half wave rectifier except that while plate A becomes positive, plate D becomes equally negative. The cathode becomes positive with plate A because current can flow to this plate while plate D at a negative polarity has no influence whatever on the voltage of the cathode. No current flows in the B-D half of the high voltage secondary during this half cycle—Fig. 15. At the end of the first quarter cycle at time T1 (Fig. 15A) the plate connected to A is at +500 volts while D is at minus 500 volts *and hence the total voltage between A and D is 1000 volts.*

The condenser is charged as usual, the current flowing through the load. However, for the next half cycle terminal D and the plate to which it is connected becomes positive while A becomes negative. The conditions at D are the same as those at the start of the second cycle of Fig. 12A except that the condenser has not had time to discharge as much as before. *Hence the condenser voltage is kept at a higher average value.* Since the condenser maintains a higher average voltage than in Fig. 12, when the next charging voltage is applied, the voltage at the plate for each half cycle must exceed this higher value before current may flow in the rectifier because for a charged condenser to take a higher charge the voltage applied to it must increase.

A line marked *average voltage of C* in Fig. 15A (left portion of figure) for normal load conditions indicate that this value is around 350 volts while in Fig. 12A it would be only a little over 300 volts. Also the average current flow as shown in Fig. 15A is above 100 ma. (at the left) while it would be somewhat lower in Fig. 12A. Note that one scale is now used to estimate both volts and current in milliamperes in Fig. 15A.

The Effect of Changing the Load Resistance

Now suppose instead of using 3542 ohms for R in Fig. 15, we use 3 or 4 times this value. For example, suppose we use 10,000 ohms instead of 3542 ohms. The current flow at the same voltage will be about one-third of what it is when using the 3542 ohm resistor. The current flow in each plate circuit of the rectifier under this condition will be correspondingly reduced and the internal rectifier plate resistance being now a much smaller part of the total resistance it will have a correspondingly smaller voltage across it. To clarify this see Fig. 15B.

With a total peak value of 500 volts across a combined resistance V1 of the tube and R1 of the load of 625 ohms for V1 and 3542 ohms for R1 (total of 3542+625=4167), there will be a peak current of 500/4167 or .12 amp. (120 ma.). Now if R is increased to 10,000 ohms shown as R2 of Fig. 15B with the resistance of the tube increasing to 800 ohms at this lower current value, the total resistance of V2 and R2 will now be 10,000+800 or 10,800 ohms. At 500 volts, there will be a current of 500/10,800 or .0463 amp. or 46.3 ma. Now the voltage across R will be 10,000× .0463 amp. or 463 volts, while that across the rectifier will be 800×.0463

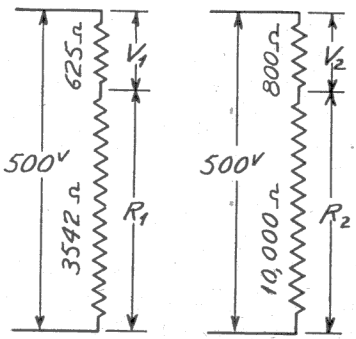


FIG. 15B

or 37 volts. Thus, if the load resistance is increased (decrease the load current) the output or condenser voltage rises from 425 volts to 465 volts. This effect is shown to the right of time T3 in Fig. 15A—denoted by the straight dash line for condenser C where you will note it has a higher average value. The average voltage is thus *increased* from 350 to about 455 volts and the current, while much less, *is more nearly uniform*. This is because the condenser discharges somewhat less rapidly through the higher resistance load, and hence requires much less additional voltage charge every half cycle to maintain its average voltage. The more current drawn from this circuit the greater the percentage of voltage and current *variation* as clearly obvious from the foregoing and from the contrast in the two sections (right and left) of Fig. 15A. One more thing to note is that for the smaller load resistor (higher load current), the internal tube voltage drop (voltage between cathode and plate while current is flowing) is higher than for the larger resistance. It is approximately 75 volts for the 3542 ohm resistor and only 37 volts for the 10,000 ohm load resistor. These are, of course, the maximum voltage values and they are less at all other points in each cycle than at peak voltage. From this it should be clear that the higher the external load resistance the more voltage there will be available for the operation of other tubes in a radio set. Thus the less voltage drop across a rectifier tube (really wasted) the more efficient it becomes.

This type of rectifier cannot easily adapt itself to compensate for sudden changes of load current nor will it *regulate itself* to maintain the load or output voltage constant for different load currents. *Hence it is said to have poor regulation*. The degree of adaptation to various loads is not strictly a fault of the rectifier tube for, as you have seen, the condenser assists greatly to maintain voltage across the load. Regulation is a characteristic of the entire power supply system, the tube only contributing a part of it.

The Addition of an Iron Core Choke

The current in either section of Fig. 15A is still not as steady or as pure D.C. as would be needed for the operation of the average A.C. receiver. As various complete filter systems will be described later on, we will show only the fundamental operation of the filter circuit in this lesson.

If the capacity of the condenser in Fig. 15 is increased, it would take longer to charge and would discharge more slowly. In this way, the output voltage of the rectifier (across R) *would tend to be more constant*. However, before the proper constancy of current flow and voltage output can be maintained the capacity value of the condenser would have to be increased out of reason. When a iron core choke (large amount of inductance) is included with condensers in a rectifier circuit, the combination of these two units is called a *filter* because the action of them is to filter out or remove the current *variations*.

The property of an iron-core choke coil to tend to prevent any change in current flow through it is used widely in the usual filter circuit so that condenser values will remain practical, and in addition the choke, plays a desirable part in the filter action. It is wired in series with the load resistor either in the positive or negative lead to the load. Refer to Fig. 16. It shows a choke coil in the positive connection to the load with an additional condenser besides the one used in the other circuits. This is by far the most common type of rectifier and filter circuit used in radio receivers.

Note that Fig. 16 shows the actual circuit with the direction of current

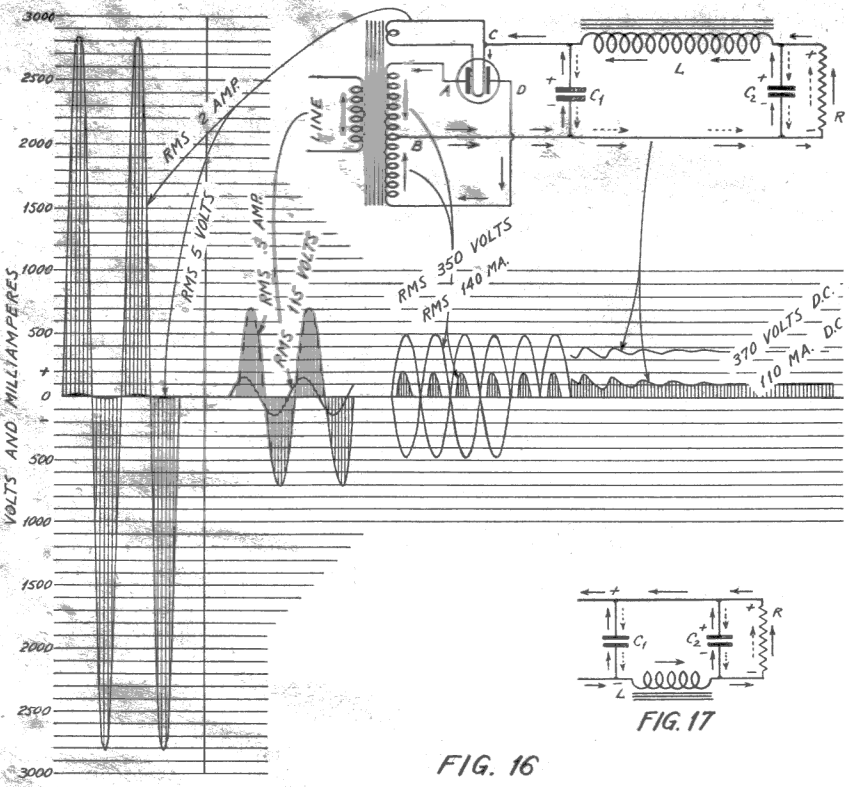


FIG. 16

FIG. 17

flow in each part of the circuit and the operating voltage and current conditions are shown graphically below the diagram.

You have studied thus far the operation of a similar circuit up to and including condenser C1, and hence we may start from this point. From Fig. 15A you can readily estimate that since the maximum rectified voltage is about 425 volts (curve C at time T1) and the minimum about 300 volts (curve C at time T2), the total voltage change is $\frac{425-300}{2}$ or 62.5 volts approximately. This is quite a large portion of the average of 350 volts; in fact, it is 100× 62.5/350 or almost 18% of the average. This difference between the maximum and the minimum voltage (62.5 volts in this case) is called the *ripple voltage* or, in some cases, the *A.C. component*. This condition would be referred to as *18% ripple*.

Referring again to Fig. 16, you will find that in order to discharge condenser C1, called the *first or input filter condenser*, it must draw current through the choke coil in the direction of the solid arrows. The condenser discharging current is indicated with dotted arrows. The condenser has no difficulty charging because the choke does not influence its charging rate, as it is not in series with this first condenser (C1) and the rectifier tube.

Any tendency for C1 to *discharge* will, of course, tend to *increase* the current through the choke L. When the voltage of C1 is maximum, the current through L tends to reduce and thus build up magnetism in it. Hence when the voltage across C1 tends to reduce, the energy in L is converted into voltage and it can maintain the voltage of C1 without

drawing an appreciable current from condenser C2 or load R. Thus the choke helps to fill in the uneven gaps of the current.

After the rectifier has operated for several cycles, the voltage of C2 (called the output filter condenser) rises to a high value, but because of the resistance of the coil L the voltage of C2 can never equal that of C1. As long as there is a load R attached, there will be some direct current flow through L and the voltage at its right terminal, Fig. 16, will be lower than that at its left.

Whereas the voltage across C1 may change as much as 18%, that across C2 cannot change more than 1 to 3% on the average. As you have seen in connection with Fig. 15A, the 18% voltage change across the filter input condenser occurred at full load. At a much lower load indicated at the right-hand section of Fig. 15A you will note that the maximum voltage is about 463 volts, while the minimum is around 445 volts, making a total voltage of $\frac{463-445}{2}$ or 9 volts. The average would be about 455 volts of which 9 volts forms only $100 \times 9/445$ or about 1.97% ripple voltage.

It should be very obvious from this that the ripple voltage (reproduced as hum in a receiver) depends to a very large extent on the value of the load current as well as on the type of filter. If the power unit circuit of Fig. 16 is loaded to maximum current, the ripple voltage across C1 would be 18%. With the choke coil in the circuit, the ripple across C2 will rarely exceed 1 or 2% at maximum load, due to the self regulating action of the choke L. At less than full load, the ripple voltage is, of course, very much less just as for the single condenser action. The ripple voltage across C2 is always a very nearly fixed percentage of the ripple across C1. For average values of L, it would be 2 to 5%. If it were as high as 5% of that across C1 when the latter is only 1.97% of the D.C. voltage produced, the output ripple voltage would be around 1/10 of of 1% and the actual ripple voltage would be less than ½ volt. This is entirely satisfactory for apparent hum free receivers and public address amplifiers and is the way we get a satisfactory D.C. from an A.C. power line.

The graph part of Fig. 16 shows the voltage and current conditions for the entire circuit. All conditions are represented on the same scale of voltage, and this scale is used as well for current in milliamperes.

In this way, the relatives values of current and voltage at various places in the circuit may be directly compared.

The following should be noted from the graph: The rectifier filament current is 4 times as large (but at reduced voltage) as the primary line current, the secondary high voltage (but with reduced current) is a little over 3 times as great as the primary voltage and the rectified output current (110 ma.) is only a little over 1/5 of the transformer primary current. The rectifier filament voltage on this voltage scale is just visible at 5 volts R. M. S. Although we have both high voltage and high current in the secondaries of the power transformer note where voltage is high, current is low and vice versa. The transformer cannot increase *power* but it can increase or decrease voltage or current. Other lessons will take this up in more detail.

Note in Fig. 16 how the ripple voltage actually tapers off as the action progresses through the choke coil. As a result, the current from the negative of C1 to the negative end of resistor R is *essentially constant*.

Very often the choke is placed in the negative power supply lead as in Fig. 17. For this wiring, the effect

on the voltage across the load R and the current through it is exactly the same as before. The choke is in *series with the load* as before, and as such it affects the current in every point of the circuit. Whereas in Fig. 16 the current leaves the load by way of the choke, it enters the load by way of the choke in Fig. 17. Since the choke L will *accept* only reasonably steady current in Fig. 16, current will be drawn through the load in a reasonably continuous form. You might think that since there is no choke between points B and load R in Fig. 16, that the current can enter R with great variation. However, remember that the positive side of the circuit determines how the current may enter from the negative side because if the positive side is opened, the current will most surely cease in the negative side of the circuit. Hence, if current is drawn by selecting its most steady portions from the positive side of the load, we cannot avoid a more constant current entering the negative side of the load. So, as far as the ripple voltage across the load is concerned, it makes no difference whatever whether the choke L is in the positive or negative lead of the filter circuit.

The largest economical sizes of capacity and inductance are used in this type of filter (Fig. 16) and current is simply forced through the filter by the application of a high voltage. To distinguish this filter from one which would take advantage of conditions of resonance at certain frequencies of the line supply, this filter is called a *brute-force* filter.

Although you will rarely ever find this filter used without the input filter condenser—that is, C1 in Fig. 16, it is sometimes used in this way, and you should know what type of operation to expect. The circuit of Fig. 18 shows the rectifier and filter with one condenser omitted. Figure 18A shows the manner in which the voltages and currents change as we

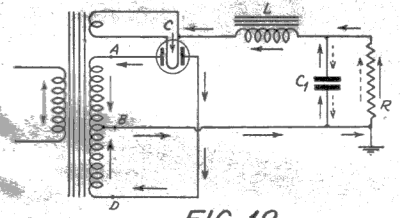


FIG. 18

have explained them for the other circuits. This is a simplified graph and there are only a few important things to notice about it. First, the cathode voltage rises somewhat higher than for the condenser filter input; second, current through the load is continuous; and third, the cathode is actually carried below ground voltage or made negative for short intervals of time. During these last mentioned intervals, rectification may continue because of a short instant the plate, though negative, is less negative than the cathode up to approximately time T1. At this point, the rectified plate current reduces. The energy placed as magnetism in the inductance during the former part of the cycle now comes into action and supplies current for the circuit.

The average output voltage across the condenser at the output of this filter, Fig. 18A, is considerably lower than for the condenser input filter as in Fig. 15A. For an average choke coil, the output voltage will be 25 or 35% lower than for a condenser filter input, using a fairly large condenser.

Characteristics of Rectifier Tubes

You are ready now to inspect the characteristics of the 80 type tube graphically. This same general picture will also hold true for other type full wave rectifiers. Figures 19 and 20 show the important characteristics in which you will be interested. Figure 19 shows the average amounts of load current drawn from the power supply. Values are given in both graphs (Figs. 19 and 20) for a num-

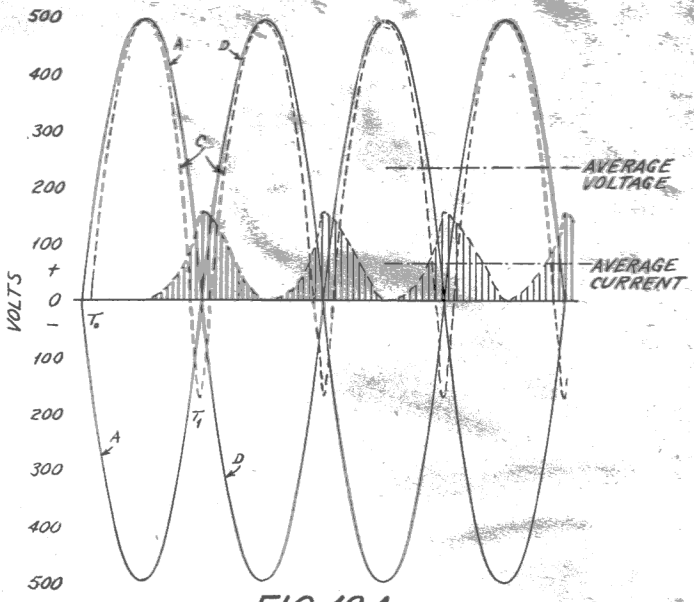


FIG. 18A

ber of applied voltages from plate to ground. Let us see what happens at 400 volts applied from each plate to ground. If 40 ma. is drawn from a circuit, such as Fig. 18, the voltage from C to ground will average 320 volts as read from Fig. 19. Note that the vertical line marked 40 ma. crosses the horizontal line marked 320 volts at 400 A.C. volts applied from plate to ground.

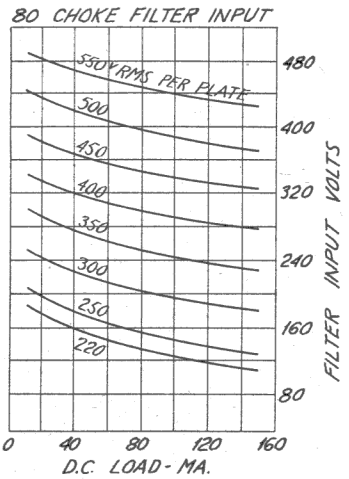


FIG. 19

For the same load conditions, *using a condenser input to the filter* (as in Figs. 16 and 17), note from Fig. 20 that the voltage at the filter input will be about 465 volts. For these two conditions note that 320 volts is less than 69% of 465 volts. Thus the filter with the condenser input gives about 31% more output voltage. When you consider that the applied voltage of 400 volts is the R. M. S. value and that the peak value would be 400×1.414 or almost 566 volts, you will realize that the maximum internal tube voltage drop for this last case is about 566—465 or 101 volts.

Although the information for Fig. 19 would seem to indicate that the internal tube voltage drop is much greater than for Fig. 20, this is not the case because the cathode voltage is very irregular for the choke coil input as indicated in Fig. 18A. While the average cathode voltage is 320 volts, at no time is the cathode as much as 100 volts more negative than either of the rectifier plates.

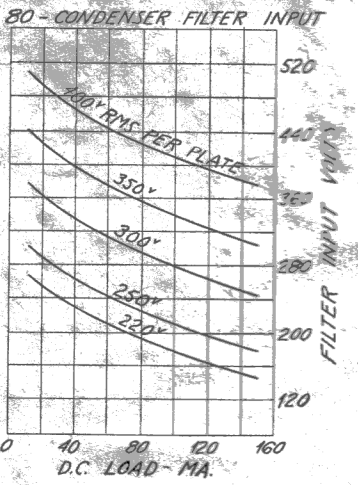


FIG. 20

Voltage Doubling Rectifier

A voltage doubling rectifier is one which does not use a power transforcer. The D.C. output of such a rectifier can be equal to twice the peak value of the A.C. input. The most commonly used voltage doubling rectifier is shown in Fig. 21. A type 25Z5 tube is used. In effect, this type of rectifier is two half wave rectifiers with the D.C. output in series. Its operation is graphically represented in Fig. 21A. Curve A of Fig. 21A shows how the A.C. input voltage changes in polarity in accordance with the 115 volt A.C. line input. It rises to a positive peak of 162 volts approximately (115×1.414) and returns to zero and then rises to minus 162 volts. To return to the rectifier circuit when point A of Fig. 21 becomes positive, it, of course, makes the plate and cathode to which it is connected positive. Accordingly, cathode D (the one through which current can flow when A is positive) rises in the positive direction as current is drawn to charge condenser C1. The manner in which this *cathode voltage rises* in the positive direction is indicated by the dash curve D in Fig. 21A. At the peak of the first quarter cycle (time T1), the condenser C1 is at full charge (highest peak voltage value it can attain) and its voltage remains relatively high, depending on the load resistance of R. Because the A.C. voltage starts to decrease, condenser C1 now slowly discharges through condenser C2 and load R. Note here that C1 and C2 are in series with the positive of C2 connected to the negative of C1. These condensers are of the electrolytic type and their effective capacity across B and D is one half the value of one condenser. At the end of the first half cycle of the A.C. voltage, (T2), point A of Fig. 21 starts to become negative. It, of course, makes the cathode (E) connected to it negative. The plate connected to A is already very much more negative than cathode D, and no further current may flow between plate A and cathode D because of the reverse polarity. Now when cathode E is made negative due to the reverse of the A.C. cycle, plate B will draw current from it. It is connected to C2. With no charge in C2, plate B will be at ground potential. When rectification is started for the second half of the cycle, charging current starts for C2 and a voltage will be built up across it. Plate B will assume the polarity of this voltage just as cathode D assumed the voltage of C1.

Cathode D rises to a positive average value, of about +130 volts at a reasonable load value, while plate B rises to minus 130 volts under identical conditions. Hence the voltage between B and D or across the load R

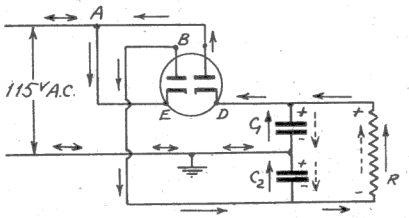


FIG. 21

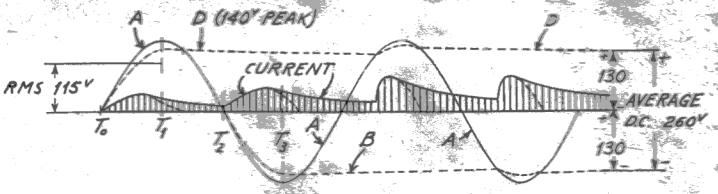


FIG. 21A

will be 260 volts, or double the rectified voltage of one plate and cathode.

To get 260 volts output from this rectifier, it would be necessary to use a load that would draw about 18 or 20 ma. and values of 16 mfd. for both condensers C1 and C2. Since this rectifier has even poorer regulation than the half wave rectifier as the load is increased the voltage across B-D will be greatly lowered. In fact, if 100 ma. is drawn through R by making it smaller in value the voltage across it would be only 180 volts. If two 8 mfd. condensers (giving an effective value of 4 mfd.) were used instead of 16 mfd. for C1 and C2 and the current remained at 100 ma., the output voltage would be only 140 volts. Under these conditions there would be little advantage in the voltage doubling system.

In addition to the foregoing facts, note in Fig. 21 that the rectifier tube must have two separate elements—that is, in effect these must be two separate rectifiers. One of the cathodes (A) has voltage of the A.C. line impressed on it, while the other (E) has a positive pulsating D.C. Likewise, plate A is connected to the A.C. line, while plate B has a negative pulsating D.C. on it. Care must be taken that the proper cathode and plate are associated, for, if the plates or the cathodes are reversed in wiring, there will be no output and no rectification. Note also that *no input power transformer* is used (this being the virtue of the system) and none is needed for ordinary service up to about 250 volts output. Of course, a power transformer can be used if desired with a tube or tubes which can carry more current.

Typical Rectifier Circuits.

In Fig. 22 is shown a common circuit making use of the *half wave rectifier system. Both plates of the 25Z5 tube are connected together* (to form a half wave rectifier) and to one side of the A.C. or D.C. line. This connection makes possible the design of an AC-DC receiver—that is, the receiver will operate on either A.C. or D.C. power lines. With A.C., operation is very much like that shown in Figs. 12 and 12A, but the power from the line is used directly instead of from a transformer.

When operated on an A.C. line, at 115 volts, the D.C. available at the filter input across C1, Fig. 22, is about 115 volts with a load current of 40 ma. through resister R (load) and the choke coil L. For these conditions, the filter condensers must

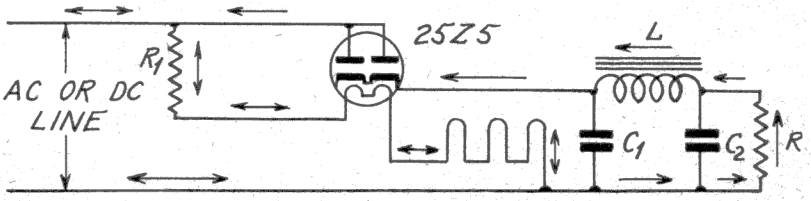


FIG. 22

The manufacture and inspection of large transmitting tubes is a costly and exacting job. The above view shows a *Westinghouse* girl inspector checking transmitting tubes before final shipment to the Navy.

have values of 8 mfd. each. When using 16 mfd. values you may expect about 125 volts, but with only 4 mfd. for each filter condenser at 40 ma. load current, only 88 volts will be available at the filter input. The resistance R, of course, is simply symbolic of the plate circuits of several tubes in parallel, which form the actual rectifier load.

No attention need be given the polarity of the power line plug when A.C. is used, but when used on a D.C. power line, the lead to the rectifier plates must, of course, connect to the positive side of the power line. The filament circuits of all tubes in the receiver represent a *series resistance load* consisting of several separate tube filaments of the same current rating connected in series across the line. Enough resistance R1 (Fig. 22)

is added to provide the correct voltage across each filament. For example, suppose a 25Z5 rectifier (25 volt filament), a 25L6 power tube (25 volt filament), a 6C6 (6.3 volt filament) and a 6D6 (6.3 volt filament) tube are used in a receiver. The total voltage required to operate these filaments in series will simply be their sum and the same amount of current (.3 amp.) flows through all filaments. Thus 25+25+6.3+6.3=62.6 volts. For an A.C. 115 volt line voltage (R. M. S.) or D.C., a resistance R1 would be needed which would give a voltage drop of 115—62.6 or 52.4 volts. It would need to carry .3 amp. Its resistance value from ohms law would, therefore, be 52.4/.3 or 175.7 ohms approximately. This would be the value of R1, Fig. 22, under the conditions.

The filaments are not electrically connected to any of the cathodes of the tubes in the receiver and their voltages do not affect those applied to the plates of the other tubes. For A.C., there is an alternating current flow through the filament circuit. For D.C., there is a direct current flow through the filaments. Either form of current will provide proper heating energy for the filaments. The filament circuit will operate for either polarity of the line, but the plate circuit of the rectifier tube will not. When power from a D.C. line is applied to the rectifier tube a direct current flows from cathode to plate through the tube. In other words, its plate circuit simply acts like any other resistance.

The voltage regulation is very excellent when D.C. is used and the tube drop is only 8 volts when the load current is 100 ma. From a minimum of 10 ma. to a maximum of 100 ma., the voltage at the filter input drops only 6 volts.

Power Dissipation of Series Filament Resistors

The power dissipated by the resistor R1 in Fig. 22 is completely wasted and attempts have been made to reduce or eliminate this power loss. At 52.4 volts and .3 ampere the power equals P=52.4×.3 or 15.72 watts. This amount of power is completely wasted in supplying a filament power of 62.6×.3 or 18.78 watts (the power which the tubes themselves require). Under this condition, out of a total power of 34.5 watts (18.78 necessary watts for filament heating) the efficiency is 100×18.78/34.5 or 54.4%.

One of the first things done about this extra series resistance was to get it out of the radio cabinet where it simply produced excessive waste heat. This took the form of a resistance wire placed in the power line cord, where it might be spread over a large area. Its temperature could then be considerably lower than usual yet it would still radiate 15.72 watts. This figure of 15.72 watts applies only to the case just outlined. The principle remains the same, however, for other tube values. Connections are made as in Fig. 23, and the line cord with the additional resistance wire (R1) is often called a *cordohm*. This does

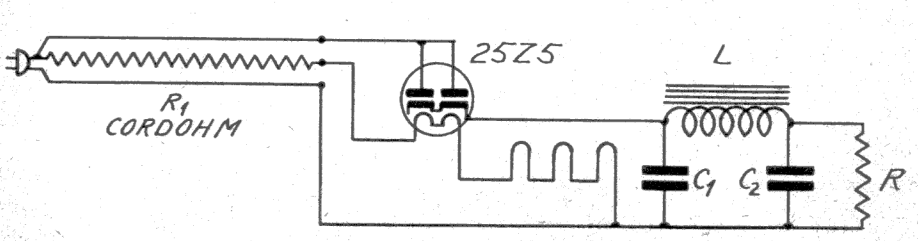


FIG. 23

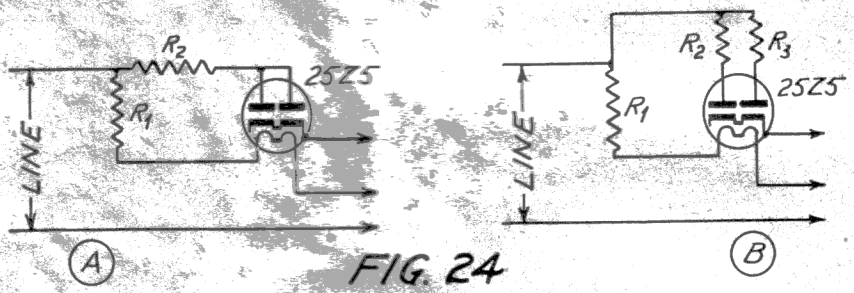


FIG. 24

not solve the efficiency problem but does solve the problem of excess heat in the receiver cabinet.

The problem of efficiency has been solved by using tubes with higher filament voltages and less filament current. For use in AC-DC sets, many such tubes have filament voltages of 12, 30, 35, 50, 70 and on up to 117 volts. Tubes are designed for particular circuit conditions. A combination of receiving and rectifying tubes for A.C-D.C. operation has a total rated voltage of from 115 to 125 volts. For this reason, the 35Z5GT and other higher voltage rated tubes are now more common than the lower voltage types.

When the A.C. power line switch is turned on for Fig. 22 or Fig. 23, there is a tendency for the rectifier tube to draw a very high current in charging the input filter condenser. Toward the crest of every positive half cycle the current through the tube becomes very large. This is clearly illustrated by the peaks of current in Fig. 12A. This large current flow has been found to be very harmful to the tube. It has been overcome through the use of a small resistance R2 (15 to 100 ohms) in series with the rectifier plates as shown in Fig. 24. At B of this figure a separate resistor is used for each plate. While this slightly reduces the maximum current which can be drawn from the rectifier, it greatly *reduces the rectifier peak current* and thus lengthens the tube life. The use of two resistors *forces* the two rectifier sections to share more evenly the total rectified current in addition to limiting the total current.

Use is even made of this resistance by arranging the circuit for a pilot light (for the tuning dial) to be used in its place. The arrangement is shown in Fig. 25 where a low voltage section of the filament (in this case, the filament has three terminals) is placed across the pilot light and the plate or plates are connected to a terminal which is connected between the two filament sections.

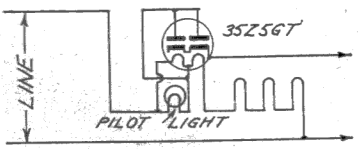


FIG. 25

In many of the earlier AC-DC sets, the speaker field coil was supplied with current from one rectifier section, while the radio set itself was supplied from the other rectifier section of a double diode tube. This, of course, was done when the field coil of the speaker was of the high voltage type requiring from 80 to 100 volts across it for operation.

Your next lesson will continue the description of rectifier circuits and tube standards. Before referring to it, however, turn to the questions of this lesson and answer them—restudy the lesson dealing with the principles involved if you have any difficulty with the questions. This lesson is most important so make sure you are satisfied with your understanding of it before passing on to the next one.

These questions are designed to test your knowledge of this lesson. Read them over first to see if you can answer them. If you feel confident that you can, then write out your answers, numbering them to correspond to the questions. If you are not confident that you can answer the questions, re-study the lesson one or more times before writing out your answers. Be sure to answer every question, for if you fail to answer a question, it will reduce your grade on this lesson. When all questions have been answered, mail them to us for grading.

QUESTIONS

No. 1. Name the three basic types of cathodes described in this lesson.

No. 2. From a D.C. viewpoint, at what time intervals is the cathode of Fig. 11 positive? (See Fig. 11A.)

No. 3. In Fig. 12, why does current through R continue to flow even though the rectifier plate is at a zero or negative voltage?

No. 4. In Fig. 12A, why does the rectifier current stop before the end of the positive half cycle long before the plate voltage becomes zero?

No. 5. In what way is the voltage output of a high vacuum rectifier tube influenced by the current drawn by the load?

No. 6. If a power transformer secondary is rated at 325 volts (R.M.S.) each side of the centertap, what would be its PEAK VOLTAGE each side of the centertap?

No. 7. Is an iron core filter choke coil equally as effective in the negative rectifier output lead as in the positive lead?

No. 8. Is more output voltage obtained from a filter with a condenser input or one with a choke input?

No. 9. What is the maximum D.C. voltage that may be expected at the output of a voltage doubling rectifier circuit?

No. 10. Does the cathode (or filament) of a rectifier tube conduct A.C., D.C. or both types of current?